Jon M. Huntsman School of Business
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Quantum Frontiers: To Boldly Go

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"All of time and space. Everywhere and anywhere. Every star that ever was. Where do you want to start?"
Dr. Who

We have lift off!

Cali Christensen started her summer at Quantum Frontiers (QF) at an intern lunch. Seated around her were 20 other interns from universities all over the country who had been selected from a pool of over 900 applicants to participate in high-tech, space-related research endeavors pushing the boundaries of various fields such as engineering, mathematics, computer science, machine learning, and physics. Cali quickly realized after the first presentation that she may be one of the only non-engineer or scientists in the room. Her internship was different from any others that QF had yet sponsored. Instead of making space-related discoveries in new science, technology, or engineering Cali had been tasked to provide recommendation for the supply chain strategy for QF's fastest growing division that designed, produced, and operated small satellites for US Department of Defense (DoD) customers. As an MBA student studying supply chain management and with background in data analytics and operations in the agricultural industry, Cali thought she was prepared to tackle the challenge head on, but she had reservations upon hearing the science-speak of the first internship meeting. Will she be able to make a difference in how supply chain decisions are made in the super high-tech world she suddenly found herself in? Where would she start and where will her summer investigation lead her? Still, what could be cooler than spending time learning about the supply chain of spacecraft?

"Somewhere, something incredible is waiting to be known."
Carl Sagen

QF Background

Quantum Frontiers started in the 1950's as a small laboratory affiliated with a local university. They quickly gained expertise and experience in designing and building parts used on spacecraft and in space exploration including lenses, telecommunication parts, and satellites. Through the years QF was at the frontiers of their area of expertise and continued to earn the confidence of their customers receiving more contracts from the government as they grew. In the 1990's, QF created an internal program of research and development that helped research and collaborative work with researchers, professors and students from around the world to further

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explore capabilities of space missions. QF had changed to meet the needs of the future as the country moved more into space.

By the summer of 2020, QF had grown to 1200 employees across three divisions. Products and service across the three divisions were all "space-related" whether it be designing and assembling satellites, ground control, or space craft parts or creating capabilities for customer to use information gathered by space craft in their scientific, military, governmental, or commercial endeavors.

In the past, QF products were usually designed, customized and assembled one-at-a-time for their customers. However, recently there had been a few products that QF's customers have been asking for more repeatedly including: custom solar panel arrays, antennas, radios used in deep-space communications, and small satellites. Small satellites are a fast-growing segment of the military and commercial space-exploration markets.

"And we all shine on, like the moon and the stars and the sun."
John Lennon

Small Satellites

In 1957, the Soviet Union launched the first man-made satellite, *Sputnik 1*, into low earth orbit (LEO). Since then, over 40 countries have successfully launched nearly 9,000 satellites. Satellites have many applications including facilitating communication and navigation on earth, exploration of space using telescopes and other lenses, and observation of earth including weather and national security surveillance. Usually semi-autonomous, satellites are essentially sophisticated computers that include subsystems that do things like generate power, control temperature, maintain direction and orientation, and facilitate communication. Typically, a satellite is distinct from the launch vehicle, usually a rocket, that gets it into space and into orbit.

Satellites are often classified depending on the risk factor of their mission ranging from Classes A to Class D. Class D satellites are the lower cost/reliability spacecraft, while Class A satellites are high cost, but highly reliable. Often times, commercial satellites with up-and-coming technologies being tested are built to the Class D level. Military satellites flying into deeper space (Geostationary orbit) could be an example of a satellite in the Class A category.

There are many different sizes of satellites, but following technology trends, satellites are increasingly smaller and lighter. Some groups call satellites under 500 kg a "small sat". According To NASA:

> *"Small spacecraft (SmallSats) focus on spacecraft with a mass less than 180 kilograms and about the size of a large kitchen fridge. Even with small spacecraft, there is a large variety of size and mass that can be differentiated.*
>
> *Minisatellite, 100-180 kilograms*
>
> *Microsatellite, 10-100 kilograms*
>
> *Nanosatellite, 1-10 kilograms*

Picosatellite, 0.01-1 kilograms

Femtosatellite, 0.001-0.01 kilograms"[1]

Another term often used to refer to small satellites that fit within specific parameter is "CubeSat". Again from NASA:

> *"CubeSats are a class of nanosatellites that use a standard size and form factor. The standard CubeSat size uses a "one unit" or "1U" measuring 10x10x10 cms and is extendable to larger sizes; 1.5, 2, 3, 6, and even 12U. Originally developed in 1999 by California Polytechnic State University at San Luis Obispo (Cal Poly) and Stanford University to provide a platform for education and space exploration. The development of CubeSats has advanced into its own industry with government, industry and academia collaborating for ever increasing capabilities. CubeSats now provide a cost-effective platform for science investigations, new technology demonstrations and advanced mission concepts using constellations, swarms disaggregated systems."*[2]

(See exhibit 3)

Smaller satellites have multiple advantages over their heavier and bigger counter parts of the past:

- Small satellites are much less expensive than a traditional larger satellite. They can range anywhere between $1-20M (versus $100s of millions or more for larger satellites)
- Small satellites are most frequently used in low earth orbit and so rocket fuel and tolerances for radiation resistant parts are reduced driving the cost down. Low earth orbit missions are typically designed to have shorter life cycles and as sometimes considered "consumable" projects with an end-of-life intention of being burned in earth's atmosphere.
- Small satellites are quicker to build. Depending on their complexity, they can be completed in a 0.5 to 4 years instead of 5 to10 years typical for larger satellites. Some commercial CubeSat developers are marketing capabilities of producing satellites is a little as a few months.
- Small satellites are easier to launch because of their form factor and weight. They can participate in rideshare programs which reduce the price of getting them into space

In spacecraft parlance, the "payload" of small satellites includes the unique mission-specific purpose of the spacecraft and the "bus" includes all other infrastructure systems of the satellite. QF has been contracted to provide either or both the bus and payload. The past few years, QF has earned contracts to assemble and deliver an entire small satellite – bus and payload. This may require extensive sub-contracting, but they have been able to build a satellite in about 3 years with costs around $5M. The past few years, they have sold between 2 to 5 satellites every year.

[1] https://www.nasa.gov/content/what-are-smallsats-and-cubesats

[2] https://www.nasa.gov/content/what-are-smallsats-and-cubesats

"Never tell me the odds."
Han Solo

Small Sat Market Trends and QF's Response

By the end of 2019, SF had positioned itself squarely as a reliable small sat provider for government customers. However, changes in the marketplace made QF leaders aware of their need to consider their market position. Smaller commercial providers of small sats began entering the market with promises of cheaper, shorter-lead-time, standardized CubeSats. While QF fit in the market of *customized* satellites, discussions about these market threats led QF leaders to realize that their customers want mission success, not necessarily customized hardware. If the commercial players could convince government buyers to consider standardized solutions at lower costs, QF might lose much of what they had built over the years. As such, in 2020 the small sat director proposed some aggressive goals:

- Reduce lead time for small sat build cycles in half.
- Plan to triple the volume of satellite projects.
- Reduce costs of satellites in half.
- Pursue projects of higher class (Class B and A) satellites.

"Take your protein pills and put your helmet on."
David Bowie

Internal Supply Chain

<u>Contracting</u>

Since most of QF's customers spend federal dollars to pay for products, QF has to compete to win contracts for each project. Obligating federal funds requires stringent oversight governed through the Federal Acquisition Regulation (FAR) and DoD spending through the Defense Federal Acquisition Regulation (DFAR). A government official that has budgetary responsibilities can initiate a *request for proposal* to complete an aspect of their mission. The contracting office works with program managers, cost analysists, and branch and division leaders to create a bid that includes details about costs, schedules, and deliverables. Different types of contracts are used (see exhibit 12).

Typically, it takes 6 to 12 months from the time that a project is proposed to when a contract is firm and work can begin. However, even with a firm contract, the government usually holds the option to cancel contracts at any point. Federal budgets and spending interests often shift with changes in political influence and power.

Programs

Each QF project is funded separately as a *program*. Most employees are assigned to work with multiple programs and allocate their time and expenses to program costs. Program sizes and the team members will vary by program, but small sat program can have anywhere between 10 to 30 members on the program team. The program team is led by a program manager; in addition to daily program direction and leading program employees, program managers also work directly with the customer to provide the deliverable and ensure the mission is successful. Programs are assigned cost analysts, technical writers, engineers, and designers as needed – on bigger programs the bulk of the program teams are engineers. Time and wages are allocated to employees based on their time allocated to their programs.

Purchasing and Sub-Contracting

Once a contract is secure and the project plan begins to solidify, program managers and cost analysts work with the purchasing and sub-contracting departments to start ordering parts to build the project. If a part is "off-the-shelf" or a standard part that can be purchased from a list of parts offered by a distributor or manufacturer, then the part can be procured directly through purchasing. The purchasing department helps the program create a Purchase Order (PO) using the bill of material (BOM) that includes all the parts required to build the project created from the specifications, plans, and engineering drawings. The purchasing department also ensures that the documentation required by the contract is in place in order to spend the customers money. Once a part is purchased using customer's funds, it is legally owned by the customer.

The sub-contracting department is involved if a needed part has to be built uniquely for the project (not off-the-shelf) or if the project leaders decides that a component of the satellite should be built out-of-house. These sub-contracted parts can be subject to many of the same issues of contracting (i.e., bid proposals, contracting types, etc.). The sub-contracting phases could take several weeks or even months just to put a firm contract in place, and it is subject to the oversight of the main contract (called the *primary contract*) QF has with their customers.

Spending federal dollars often requires that purchasing and sub-contracting personnel navigate the primary contractor's requirements in order to ensure audit trails and part traceability. Many contracts specify that parts can only be purchased from trusted and approved vendors and manufactures in order to ensure workmanship quality, avoid counterfeit parts, and to deter the possibility of parts that can be later by controlled by enemies-of-the-state. However, not all contracts have these requirements and there can be a significant cost difference between original equipment manufacturer (OEM) and generic parts especially among general electronic parts (called triple-E, (EEE) parts).

Each program purchases their own parts, but projects across programs often use common parts. Additionally, some part manufacturers require a *minimum-buy-commitment* (min-buy) that is usually much bigger than what one program will need. In these cases, programs are often forced to either buy much more than they need or to negotiate with the vendor to pay a much higher price per part. Finally, some purchased electronic parts are made in large batches by manufacturers; if a program timing doesn't coincide with a batch production timing, the lead times for the next batch could be 6 to 9 months. These long-lead times lead program managers to scramble trying to find parts from other vendors, programs, or other government contractors – sometimes they can find a solution but often they have to wait until the next batch is manufactured.

Parts and sub-contracts are purchased using program funds released by customers at times specified in the contract. Common parts that are used across programs can only be purchased together if they are in the same procurement phase, otherwise parts have to be purchased when there is program-specific funding. There are little overhead operating funds (non-program specific funds) set aside for parts inventory because pre-purchasing parts would require QF to float the cost of parts until the program money is released. Additionally, parts that are bought with a specific program's funds cannot easily be transferred to a different program because contractually the government customer owns the parts once they have been paid for. Transfer of parts between programs can take days of programs managers time and involve multiple levels of contracting officials both at QF and the government – all parties agree that it is best avoided.

Savvy program managers may be left waiting for long-lead parts and so have started to figure ways around the program-specific procurement issues. Anecdotally, long-lead-time parts are known across program managers and engineers and so programs ask for money at earlier phases of the contract to begin buying these parts at the onset of projects. Parts are not paid for until after they are received (net 30) and so some managers have found ways to shift ownership of parts between programs before parts are paid for.

Additionally, QF leadership has begun to issue small investments for parts that have anticipated long-lead times and may hold up the project if programs have to wait to submit an order until the funds are released. These *dedicated stock* parts are then owned by QF, not the program, until the program funds can cover them. The risk in these approaches is that a government contracts can be severed without warning and without full payment; if a program manager pre-purchases parts for a program that is cancelled, QF will be stuck with the inventory without promise of repayment by a program contract.

Shipping and Receiving

When a part arrives as QF, shipping and receiving personnel ensure that parts on the shipping log are included in the shipment. Shipping documents are scanned as an attachment to the POs. Larger parts are usually picked up by a member of the program. Technical and electronic parts usually go to Quality Assurance (QA) and then are stored in the stockroom.

Quality Assurance

Quality Assurance checks for workmanship of some received parts and enters smaller electronic parts into a homegrown inventory tracking database called Parts and Material System (PAMS). PAMS allows QA to enter expiry dates and traceability information if the PO indicates that the contract requires it. All employees can look at and use PAMS and have different permissions depending on their needs. Recently the director of QA has expressed concerns for the potential of counterfeit parts entering QF.

Stockroom

The stockroom is equipped to store electronic parts that are electrostatic-sensitive and allocates space for each program to securely store parts. The stockroom employees enter data into PAMS and requisition out the materials to programs as requested. Programs can see on PAMS what parts are in the stockroom and once all the parts to build a printed circuit board (PCB) are received into the storeroom, the program can order a “kit” to be made and sent next door to the Electronic Assembly Service Center (EASC) for surface mounting circuit board production.

The stockroom also manages an area of “common stock” that include parts that designers and engineers use in early prototyping efforts. The use of these materials that are not usually allocated to project specific budgets. These parts include wires, cable, and small hardware (screws and nuts). If a program needs these types of parts for a project, they are asked to order them separately so as not to drain the common stock.

Internal Production/Testing Facilities

To help assemble their project, most programs use internal facilities including the Electronics Assembly Service Center (EASC), the Machine Shop and the Testing facilities. Each of these internal facilities are built to be "Prototype"-like shops in order to work on one or two of an item at a time. These facilities charge their time and parts to the programs for which they are making pieces.

The EASC assembles PCBs that go in projects across Quantum Frontiers. Setup times for PCBs can vary from a couple of hours to as long as a week depending on the complexity of the board and the parts used. The primary machine used by the EASC is designed for high production of the same board, so the time to produce one board is usually small compared to the setup time. Having the EASC in-house is paramount to the innovation mission of QF; if initial designs do not function as planned a redesign can be printed fairly quickly. Recently, the EASC has had backlog in requests and meets regularly with program managers to prioritize tasks.

The Machine Shop has a variety of machines and tools to form metals with high accuracy and quality. Time for projects in the shop average about one week. Designers work with engineers to submit CAD drawings to the shop for fabrication. Similar to the EASC, the Machine Shop has recently been backlogged with complex and sensitive projects and so it has farmed out some easier and less critical jobs to local metal shops.

Before being sent to space, small satellites go through extensive pre-flight testing to make sure the major functions are working properly. Complete subsystems or whole spacecraft are sent to facilities to test performance aspects like communication capabilities, GPS accuracy, proper deployment of solar panels, light and star tracking, etc. Specialized testing labs have been built to test and calibrate each deliverable. These include shake tests, radiation test, sound tests, etc. These labs have been used for decades to ensure mission success.

Assembly and Support

When all of the pieces have arrived and been fabricated by the internal facilities each program will assemble their piece. Sometimes when a program is a piece of a larger contract (called a subprime) they will "integrate" the contract with pieces from other suppliers. Contracts will usually include test pieces that are made specifically to check the integrity and quality of the research and innovation being created. QF specializes in providing the entire mission, from idea, design, assembly, integration, and support once the project is complete. This includes service or maintenance support for the life of the deliverable. This builds on the heritage at QF.

“Some people call me the space cowboy…”
Steve Miller Band

Stay on Target…

As a new intern with an assignment to consider recommendations for QF’s supply chain, Cali had access to interview employees at all levels. After a month, her understanding of space-jargon had improved, but identifying the most important element of a supply chain strategy was proving challenging. Her notes included the following:

- Program managers complain about not having the parts when they need them. Sometimes long-lead time parts hold up a project. Other times they just did not order enough of the right screw and have to place a new order delaying the program by 10 days for a $2 part.
- Cost analysts confirm that these delays are costly. A rough estimate often used to estimate the cost of waiting is to consider the cost of employees on the program team that are waiting for a part.
- Min-buy requirements also seem to be a headache for program managers. Program managers tell stories of needing two capacitors of a certain type but being forced to buy 100. They also know that their neighboring programs have extra parts, but can’t easily transfer them.
- Employees of the purchasing department report that they have placed multiple orders from different programs to the same vendor on the same day.
- While the demand for small satellites is going up, getting an actual forecast for production doesn’t seem standard protocol: production forecasts have never really been performed at an enterprise level. There are forecasts for revenue that are used for growth planning.
- The “bus” of the small satellite is slowly becoming standardized across QF. Some senior engineers talk about module architecture as a solution to supply chain problems.
- Individual programs typically research necessary parts and then follow up on placed orders while they are waiting for parts. For example, one supplier calls one of the program managers to ask about future orders so that they can add them to the production plans. She may have a general idea of upcoming needs and passes those on to suppliers.
- No one has ever analyzed data from QF’s inventory system (PAMS) to quantify the impact of inventory decisions.

Reporting these notes out to the head of the division, the two decided to dig a bit deeper into the inventory issue. As a case study, they decide to investigate the parts that belong to just one PCB that is planned to be used as a common card in all QF satellites going forward.

"Curiosity is the essence of our existence"
Gene Cernan

Avionics Stack

JOLT Avionics Stack

JOLT is the name given to the "stack" of PCBs that run the bus of small satellites made by QF. The design for the different cards has historically been handed from one program manager to the next for over 20 years. In the past, each program made necessary design changes, which has made each bus slightly different in design and execution. The JOLT Stack consists of cards that operate the power sources, command, propulsion, and communications of the bus.

Anticipating an increasing demand for more spacecrafts with shortened lead times, QF put together a team called the JOLT Service Center (JSC) that would operate across programs and focus on the Avionics of the JOLT bus, creating a standard design that could be used across all programs while still allowing for some customization if needed. One goal of the JSC is to use standardized common parts where possible. The JSC put together one master bill of material (BOM) for each of the Avionics cards and going forward will design, assemble, and manage the cards. The center charges the programs a fee to design and build the stack and maintain an updated version of the avionics. Small Sat programs are charged for the JOLT Service Center in the same way they are charged for using the EASC or Machine Shop.

SBC Card Data

One card in the JOLT avionics stack, the single board computer (SBC), has 85 parts varying from the solder and different resistors to the processor that runs it. This board costs about $20,000 dollars in parts and can take weeks to build once the parts have arrived. Testing and calibrating the spacecraft can take months, but once one build has been approved and tested the testing may require only a quarter of that time.

Data pulled from PAMS revealed some interesting facts about the parts used in this card. Over 70% of the parts come from three main suppliers which together account for less than one percent of the dollars spent on all these parts. Over 75% of the costs come from two companies which are together less than 2% of the total number of parts on the board.

The parts that are used in this particular card were also used across 109 additional programs at QF over the past five years. During that time, over 50,000 individual pieces of the BOM parts list were ordered valuing over $8.8M. The average lead time for these parts (from PO date to received date) was about 30 days but the longest lead times was 252 days. Over 60% of the parts have more than a 4-month lead time.

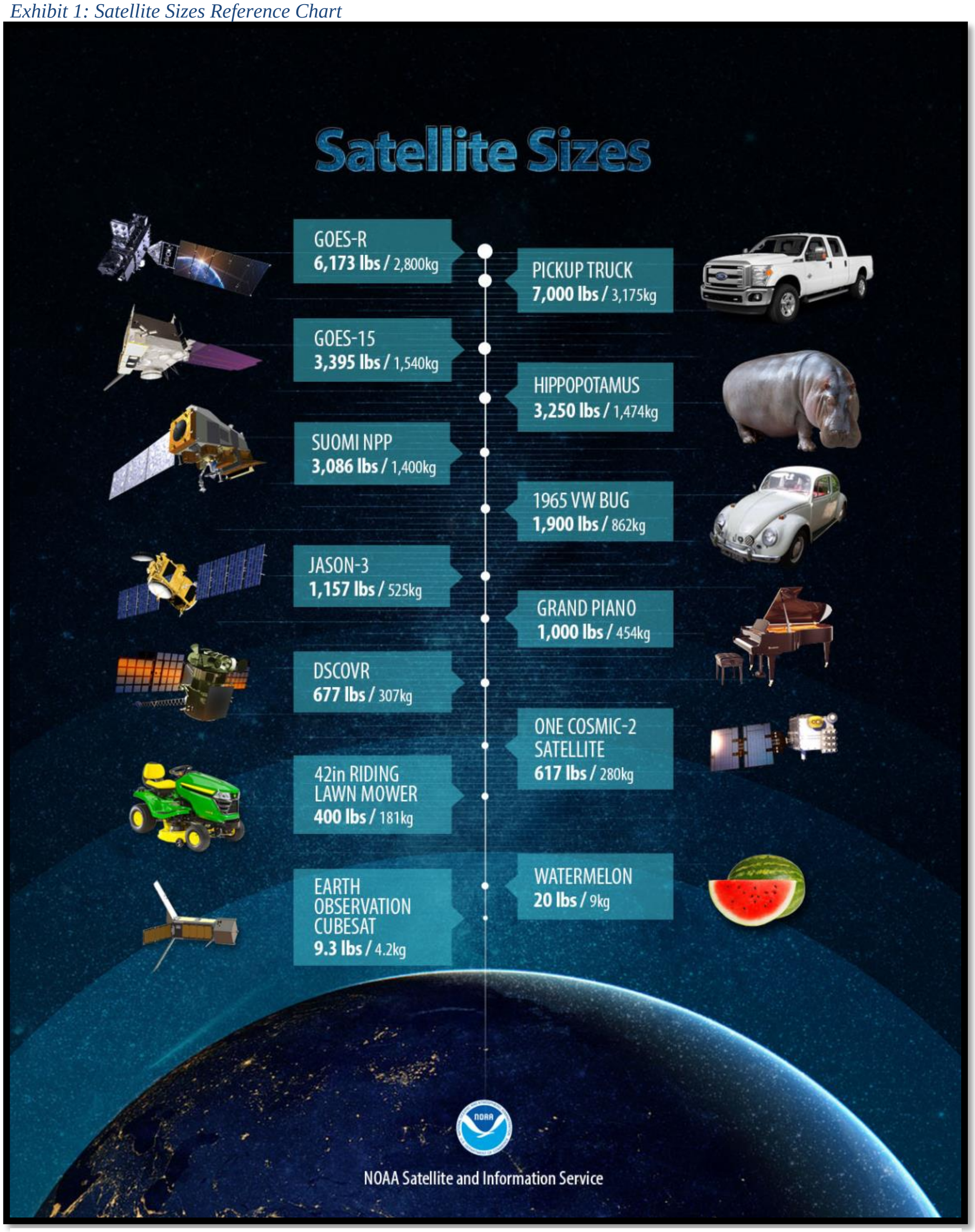
"Insufficient facts always invite danger."
Spock

Houston, we have a problem

Having received the PAMS data on the JOLT SBC card, Cali wonders what to suggest to QF leaders concerning their supply chain challenges. What more can she do with the data to better understand the issues at hand? Can she use the data to make a case for change? What should be changed? And how would she know a change would lead to improved lead times? What is the best way forward for QF's supply chain?

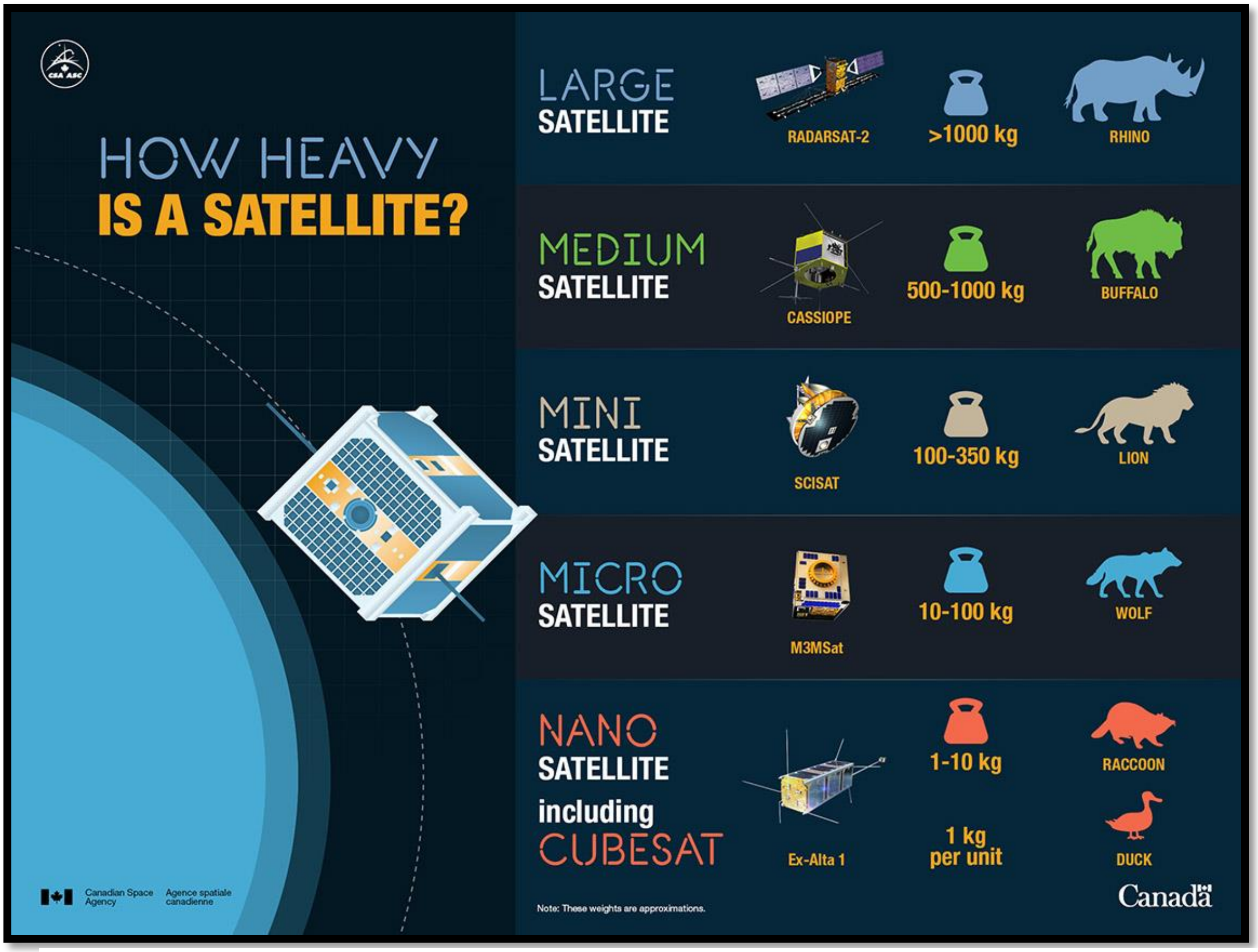
Exhibits

Exhibit 1: Satellite Sizes Reference Chart



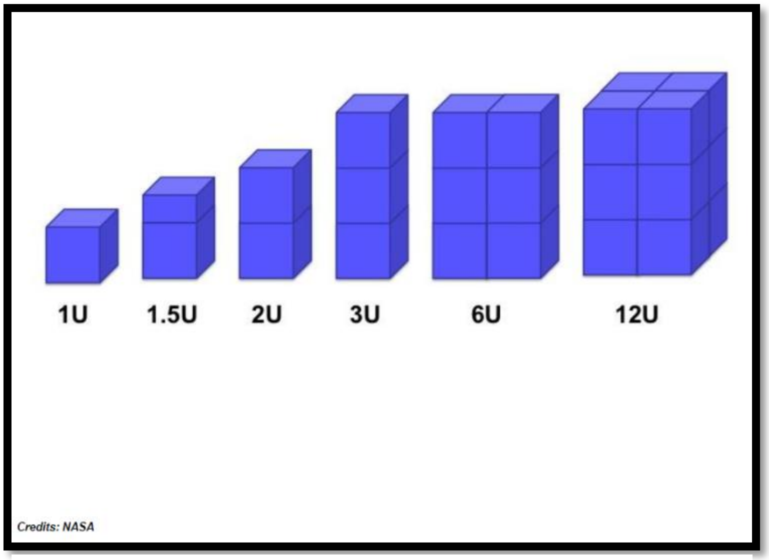
Source 1: https://www.nesdis.noaa.gov/content/satellite-technology-how-big-satellite

Exhibit 2: How Heavy is a Satellite?



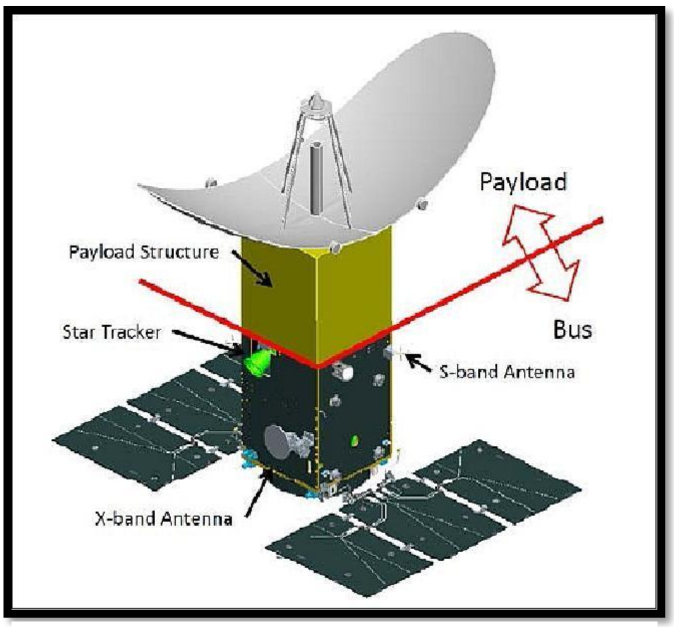
Source 2: https://www.asc-csa.gc.ca/eng/satellites/cubesat/what-is-a-cubesat.asp

Exhibit 3: Cubesat Sizes



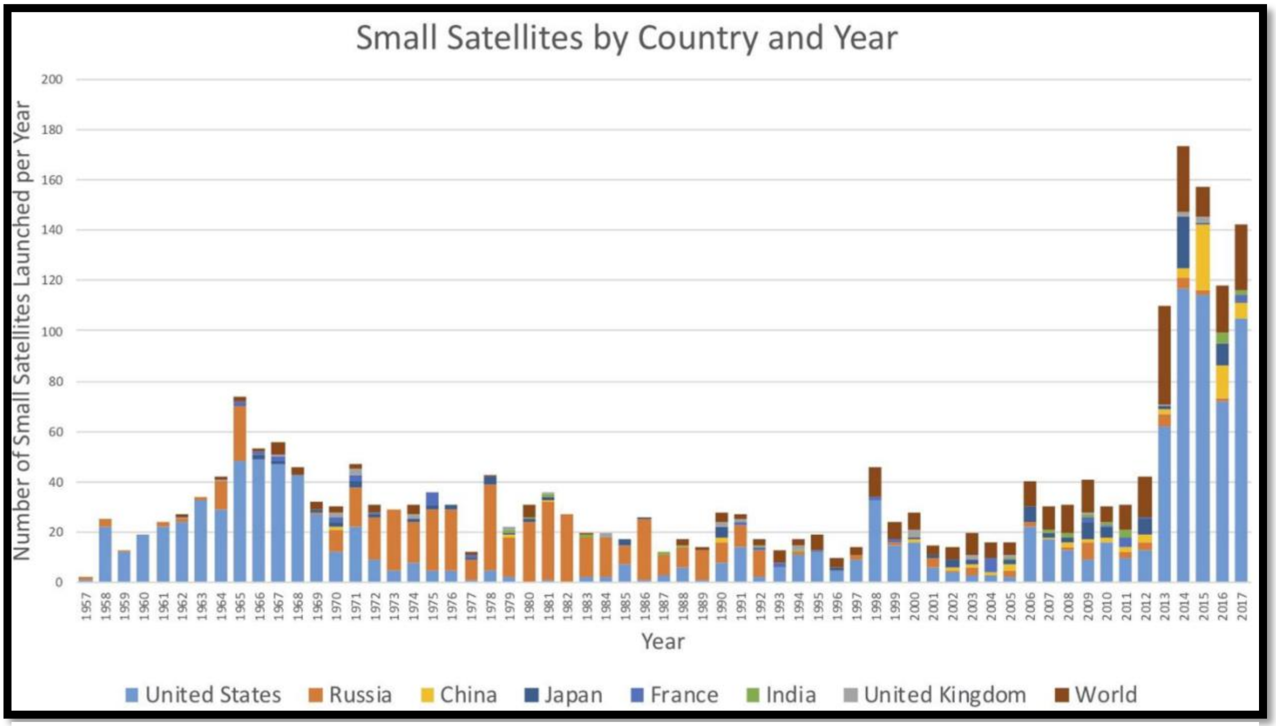
Source 3: https://www.nasa.gov/content/what-are-smallsats-and-cubesats

Exhibit 4: Payload vs. Bus



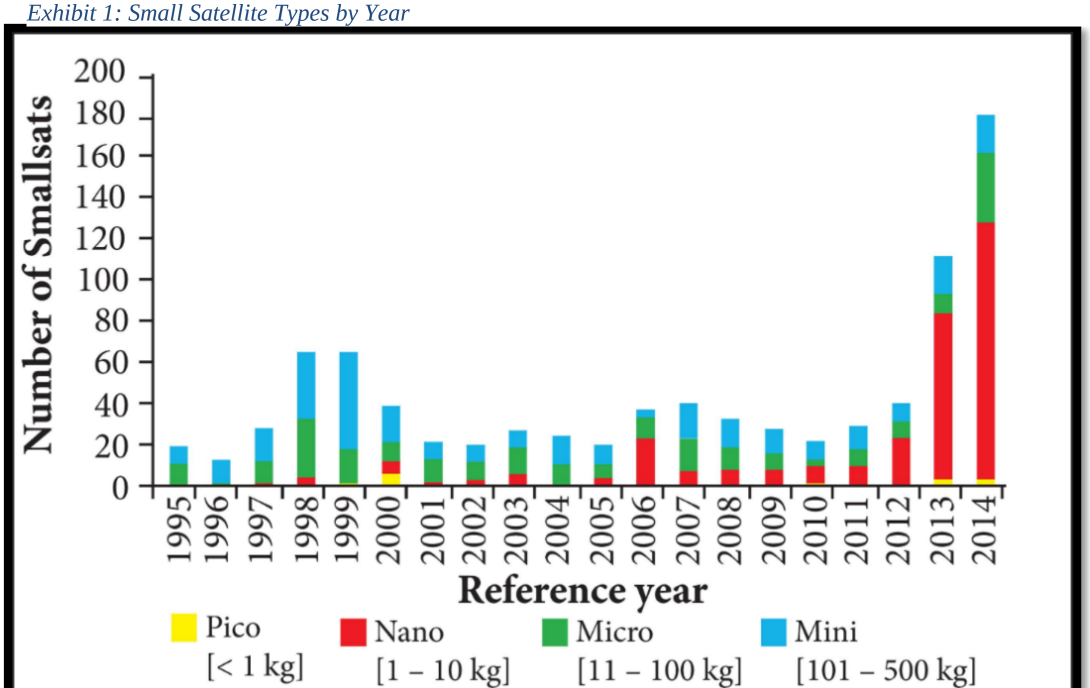
Source 4: https://www.openpr.com/news/1989145/satellite-payload-market-2020-global-industry-analysis

Exhibit 5: Small Satellite by Country and Year



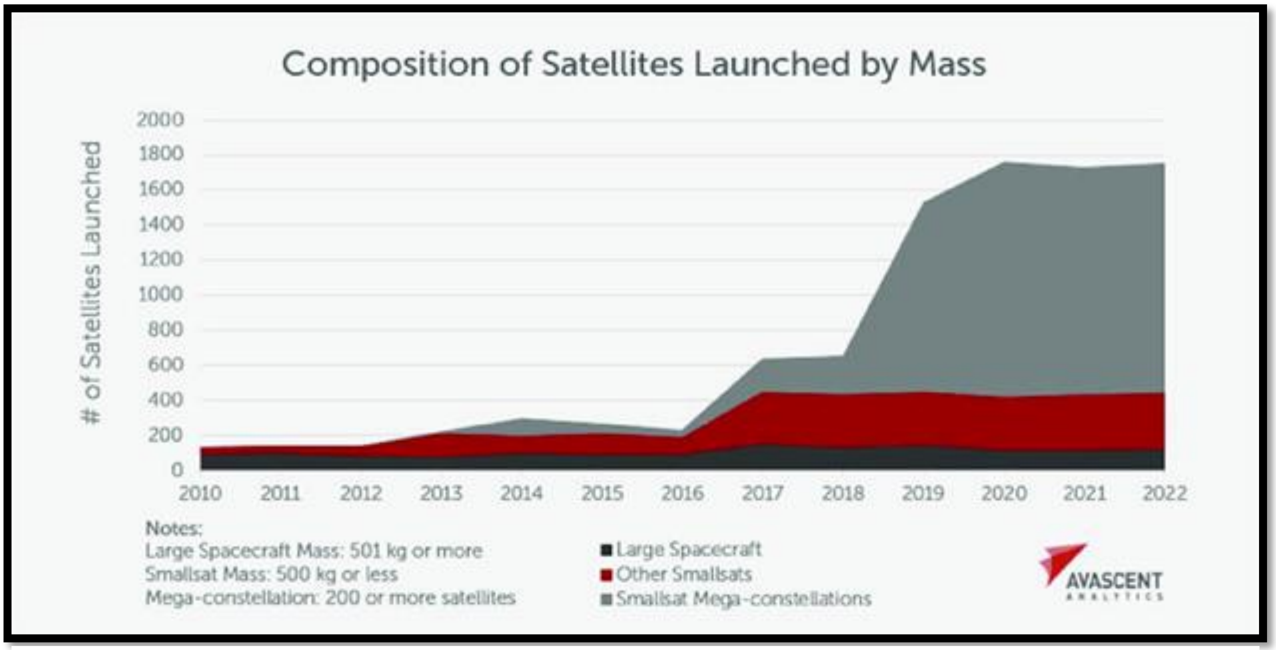
Source 5: https://www.sciencedirect.com/science/article/pii/S0273117719305411

Exhibit 1: Small Satellite Types by Year



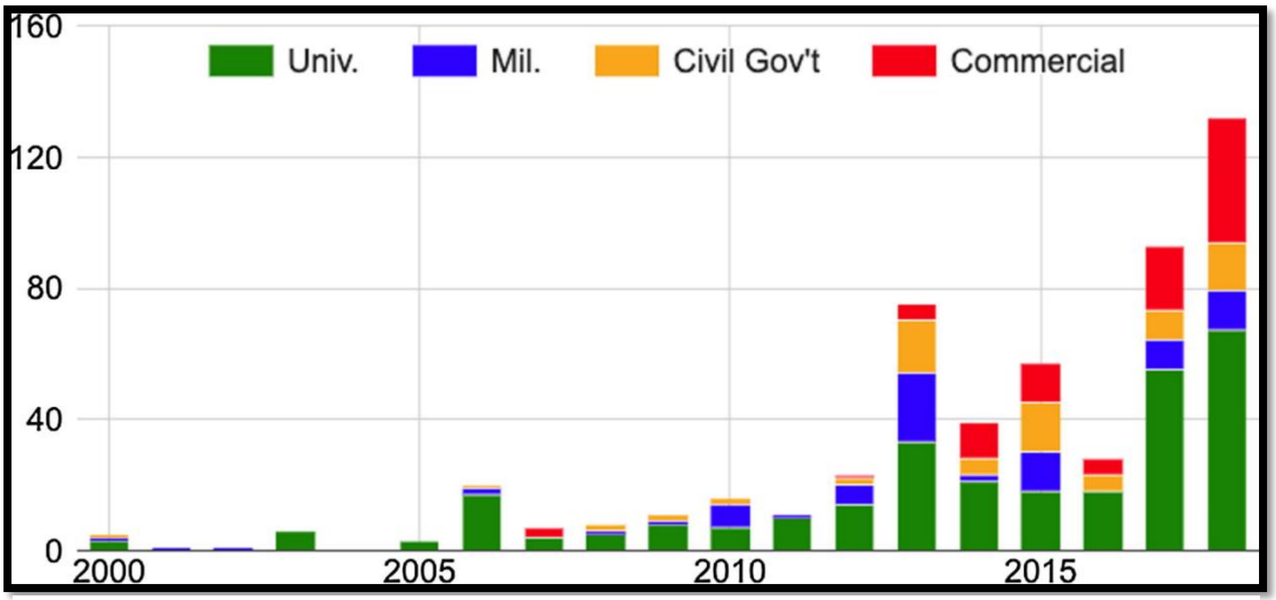
Source 6: https://www.scielo.br/scielo.php?script=sci_arttext&pid=S2175-91462017000300269

Exhibit 2: Small Satellite Types by Year



Source 1: https://www.researchgate.net/figure/Forecasted-Growth-in-Satellites-Launched_fig1_320911449

Exhibit 8: Major Groups Launching Satellites by Year



Source 8: https://www.researchgate.net/figure/Forecasted-Growth-in-Satellites-Launched_fig1_320911449

Exhibit 9: Overview of Satellite Missions

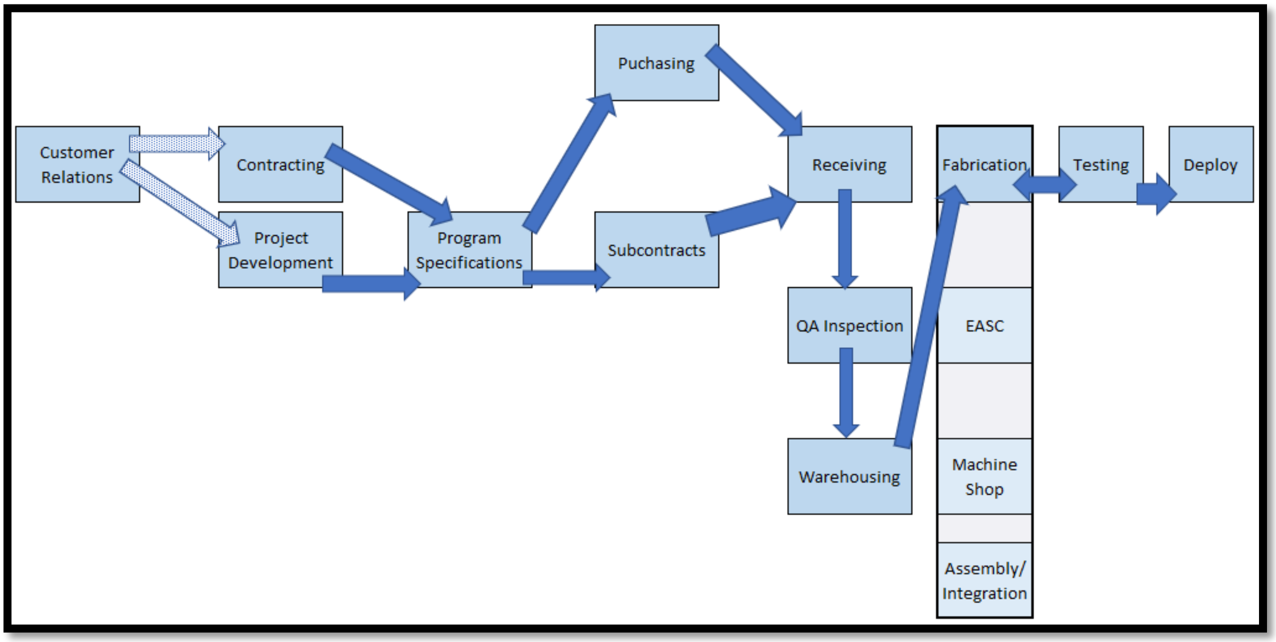
Table 2 Overview of deployed (from 1995 onwards) and announced Smallsat constellations

	Constellation name (prganization, country)	Number of deployed satellites	Planned number of satellites	Wet mass	Application	First satellite deployment
Operational Constellations	(Koudelka 2015)	6	6	8 kg	Astrophotometry of stars	02/2013
	Disaster Monitoring Constellation (DMC International Imaging International) (Kramer 2016b)	8	8	50-268 kg	Emergency Earth imaging for disaster relief 2.5 m and 5 m GSD	11/2002
	exactView Constellation (exactEarth, Canada) Macikunas and Randhawa 2012; Miler and Bujak 2013)	10	10	100 kg	Automatic Identification System (AIS)	07/2012
	Flock-1 (Planet Labs, US) (Safyan 2015; Kramer 2016a)	99	Up to 500	3U Cubesats	Earth observation with 3-5 m GSD	01/2014
	Globalstar (Globalstar, US) (Richharia and Westbrook 2010)	72	72	450 kg	Satellite phone and low-speed data communication	02/1998
	Gonets D1 and M (Government, Russia) (Zak 2016a)	12/10	12/18	225-280 kg	Store and dump communication	02/1996, 12/2005
	Kosmos (Military, Russia) (Zak 2016b)	30*	-	220-240 kg	Various, military	-
	Orbcomm OG1 and OG2 (Orbcomm, US) (Spaceflight101 2016)	35/6	35/18+30	40/172 kg	Machine-to-machine communication	04/1995, 06/2008
	Rapideye (BlackBridge AG/Planet Labs, Germany/US) (Sandau et al. 2010)	5	5	150 kg	Multispectral imagery with 6.5 m GSD	08/2008
	Sense and Stratos (Spire, UK/US)(Barna 2015)	17	20/125	3U Cubesats	Maritime intelligence and weather data	08/2013, 2015/2018
	Terra Bella Constellation (Google, US) (Murthy et al. 2014)	7	24	120 kg	High-resolution Earth observation with ≤1 m GSD	11/2013, 2016
Constellations under development/announced	BlackSky Constellation (BlackSky Global, US) (Blacksky Global 2016)	1	2/4/60	50 kg	Global satellite imagery with 1 m GSD	2016/2019
	CICERO (GeoOptics, US) (Wagenen 2016) (Jasper et al. 2013)	0	6/12/24	100 kg	Climate and atmosphere observation	2017
	UrtheDaily and OptiSAR (UrtheCast and OmiEarth, Canada and US) (Wood 2016)	0	8 / 16	Smallsats	Optical and synthetic aperture radar with 1.1 and 5.5 m GSD	2017-2020
	LeoSat Constellation (LeoSat, US) (LeoSat™ 2017)	0	78	Smallsats	High-speed data transfers using intersatellite links	N/A
	N/A (OneWeb, US) (Foust 2015)	0	648-900	125-200 kg	Broadband Internet connection	2018-2019
	PlanetiQ Constellation (PlanetiQ, US) (David 2016)	0	12/18	6U Cubesats	GPS radio occultation for weather data	2017
	N/A (Samsung, Multinational) (Khan 2015)	0	4,600	Micro-Satellites	Broadband Internet connection	N/A
	N/A (SpaceX, US) (Selding 2015b)	0	4,000	Smallsats	Broadband Internet connection	N/A
	QB50 The von Karman Institute (Scholz 2015)	0	50	Cubesats	*In-situ* measurements in the lower thermosphere	2017
	Satellogic Constellation (SatellogicArgentina/US) (Henry 2016)	2	6/16/300	35 kg	Real-time imaging of the entire Earth with 1 m GSD	04/2014, 2017

*Kosmos satellites were deployed in the period between 1995 and 2014. Part of these Smallsats may belong to military satellite constellations, however, there is a Russian policy of assigning Kosmos names to all military satellites reaching orbit.

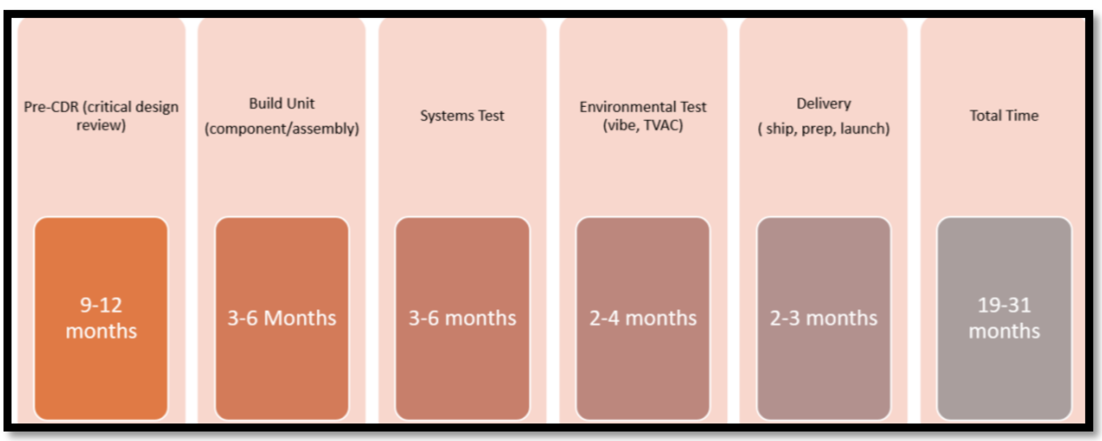
Source 9: https://www.scielo.br/scielo.php?script=sci_arttext&pid=S2175-91462017000300269

Exhibit 3: QF Work Flow



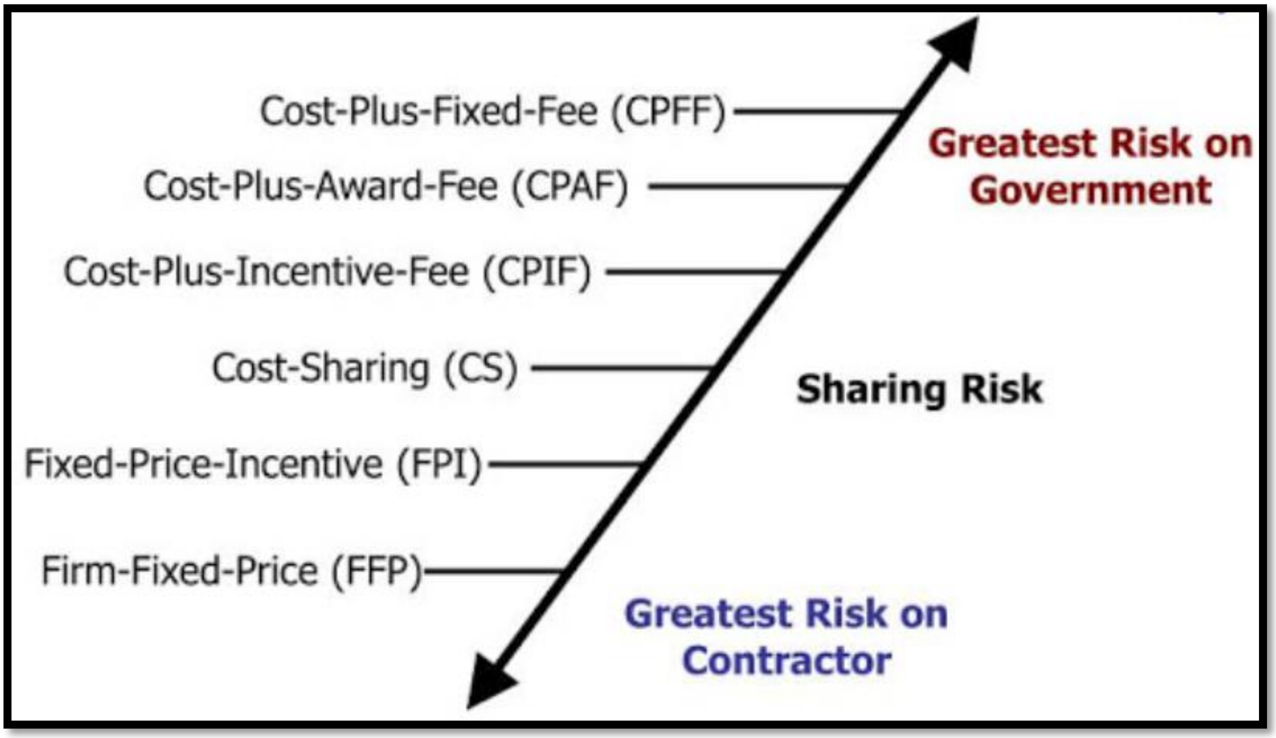
Source 2: Developed by Case Writers

Exhibit 11: Typical Small Sate Build Process Timeline at QF



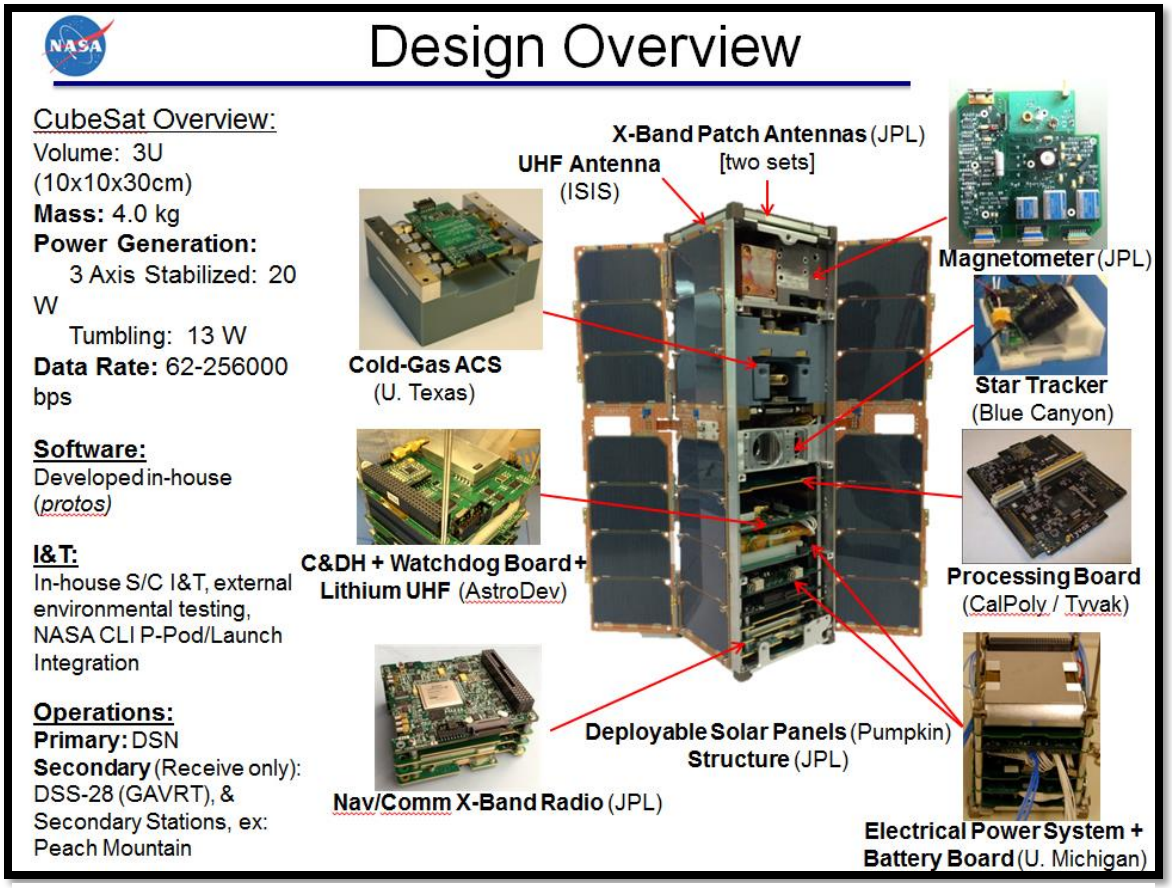
Source 11: Developed by Case Writers

Exhibit 12: Government Contracts and Risk



Source 12: http://www.dhg.com/Portals/0/headers/industries/government-contracting/Contract%20Types%20and%20Related%20Risks.pdf

Exhibit 13: Example of cubesat design and parts



Source 13: https://www.jpl.nasa.gov/cubesat/missions/inspire.php

Exhibit 14: Terms and Definitions (3Pages)

Term	Definition
Bill of Material	A list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, parts, and the quantities of each needed to manufacture an end product.
BOM	Bill of Material
Bus	The bus is the infrastructure of the spacecraft, usually providing locations for the payload.
Carl Sagen	An American astronomer, planetary scientist, cosmologist, astrophysicist, astrobiologist, author, and science communicator. His best known scientific contribution is research on extraterrestrial life, including experimental demonstration of the production of amino acids from basic chemicals by radiation. Sagan assembled the first physical messages sent into space: the Pioneer plaque and the Voyager Golden Record, universal messages that could potentially be understood by any extraterrestrial intelligence that might find them.
Class A, B, C, D	Different classification of satelittes that rate the risk associated with failure.
Common Stock	Parts purchased that can be used in prototyping and early design efforts. Common stock are overhead costs.
CubeSat	A small satellite that is in cube shape typically in U units. See U.
David Bowie	A rock star from the 70's. Please listen to Space Oddity.
Dedicated Stock	Parts purchased that are intended for a specific program, but that is purchased before program funds become available.
Defense Federal Acquisition Regulation (DFAR)	The primariy regulation for acquisition of supplies and services with appropriate funds withing the DoD.
Department of Defense	The United States Department of Defense is an executive branch department of the federal government charged with coordinating and supervising all agencies and functions of the government directly related to national security and the United States Armed Forces.
DoD	Department of Defense
Dr. Who	A British science fiction television programme produced by the BBC since 1963. The programme depicts the adventures of a Time Lord called "the Doctor", an extraterrestrial being, to all appearances human. The Doctor explores the universe in a time-travelling space ship called the TARDIS. Its exterior appears as a blue British police box, which was a common sight in Britain in 1963 when the series first aired. Accompanied by a number of companions, the Doctor combats a variety of foes while working to save civilisations and help people in need.
EASC	Electronics Assembly Service Center

Term	Definition
Federal Acquisition Regulation (FAR)	The FAR is the primary regulation for use by all executive agencies in their acquisition of supplies and services with appropriated funds.
Gene Cernan	An American astronaut, naval aviator, electrical engineer, aeronautical engineer, and fighter pilot. During the Apollo 17 mission, Cernan became the eleventh person to walk on the Moon. As he re-entered the Apollo Lunar Module after Harrison Schmitt on their third and final lunar excursion, he was the last person to walk on the Moon.
Han Solo	A character in Star Wars, I have a bad feeling about this.
Houston, we have a problem	A popular but erroneous quotation from the radio communications between the Apollo 13 astronaut John ("Jack") Swigert and the NASA Mission Control Center ("Houston") during the Apollo 13 spaceflight, as the astronauts communicated their discovery of the explosion that crippled their spacecraft. The words actually spoken, initially by Jack Swigert, were "Okay, Houston, we've had a problem here."
John Lennon	An English singer, songwriter and peace activist who gained worldwide fame as the founder, co-lead vocalist, and rhythm guitarist of the Beatles. His songwriting partnership with Paul McCartney remains the most successful in musical history. See the song "Instant Karma"
Lead Time	The time it takes to receive a part or product after it is ordered, or the time it takes to produce a product.
Low Earth Orbit (LEO)	An Earth-centred orbit with an altitude of 2,000 km (1,200 mi) or less (approximately one-third of the radius of Earth), or with at least 11.25 periods per day (an orbital period of 128 minutes or less) and an eccentricity less than 0.25. Most of the manmade objects in outer space are in LEO.
PAMS	Parts and Materials System. Homegrown parts tracking system.
Net 30	Net 30 is a term included in the payment terms on an invoice. It indicates when the vendor wants to be paid for the service or product provided. Nnet 30 means the vendor wants to be paid within 30 full days of the invoice date.
Overhead costs	Costs that are not program specific.
Payload	The portion of a space craft that includes mission specific components, typically space experiments or instruments.
PCB	Printed Curcuit Board
PO	Purchase Order

Term	Definition
Printed Curcuit Board	A printed circuit board (PCB) mechanically supports and electrically connects electrical or electronic components using conductive tracks, pads and other features etched from one or more sheet layers of copper laminated onto and/or between sheet layers of a non-conductive substrate. Components are generally soldered onto the PCB to both electrically connect and mechanically fasten them to it. Printed circuit boards are used in all but the simplest electronic products.
Purchase Order	A purchase order (PO) is a commercial document and first official offer issued by a buyer to a seller indicating types, quantities, and agreed prices for products or services. It is used to control the purchasing of products and services from external suppliers.
QF	Quantum Frontiers- a space technologies company
Small Sat	Short for Small Satellite
Small Satellite	Satellites that are less than 180 killograms.
Spock	A character in Star Trek, live long and prosper.
Stay on target…	Referecne to a line in Star Wars. Watch more Star Wars.
Steve Miller Band	An American rock band formed in 1966 in San Francisco, California led by Steve Miller on guitar and lead vocals. The group had a string of mid- to late-1970s hit singles that are staples of classic rock radio, as well as several earlier psychedelic rock albums.See the song "The Joker."
U	Unit (10cm by 10cm) used in describing Cubesat size. E.g., 1U, 3U, 6U, 12U

Source 14: Various Internet Sources Including Wikipedia

References

https://www.mda.mil/system/system.html
https://www.sciencedirect.com/science/article/pii/S0273117719305411
https://www.researchgate.net/figure/Forecasted-Growth-in-Satellites-Launched_fig1_320911449
https://www.scielo.br/scielo.php?script=sci_arttext&pid=S2175-91462017000300269
https://www.sciencedirect.com/science/article/pii/S0273117719305411#f0020
https://www.nasa.gov/content/what-are-smallsats-and-cubesats
https://www.nasa.gov/feature/goddard/2019/tiny-nasa-satellite-will-soon-see-rainbows-in-clouds
http://www.dhg.com/Portals/0/headers/industries/government-contracting/Contract%20Types%20and%20Related%20Risks.pdf